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Observing resilience within a large technical system

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Abstract: This paper introduces some of the results of an empirical field study within a large technical system (high pressure gas transmission network), exploited by one company, in which safety results from a combination of anticipation and resilience obtained by a 'mixture' of individual expertise, team coordination and organisational context favouring the tasks carried out at the 'sharp end'. High pressure gas transmission presents itself as a network of pipelines for which one threat are 'external aggressions', such as damages occurring when tractors dig, for instance, trenches for civil, municipal or urban engineering projects. In a first section, some elements of definition of 'large technical system' (LTS) is provided; it introduces some of the specific features met in these types of systems. In a second section, after a presentation of the methodological and theoretical elements, a description of the safety measures designed within this LTS for prevention of external aggression is offered. In a third section, a first and heuristic (for further developments) model of resilience, inferred from observations and interviews, and inspired from the literature on 'macro cognition' and 'collective mindfulness' is presented. Finally, in a last section, some thoughts about the translation from description to action ('engineering') of resilience (whether creating, maintaining or improving resilience) are suggested.

1. HIGH PRESSURE GAS TRANSMISSION AS A LARGE TECHNICAL SYSTEM (LTS)

This paper presents some of the results of an empirical study investigating the way in which safety is produced in normal operation within a 'large technical system' (LTS) in charge of high pressure gas transmission. The analytical category of LTS was developed about twenty years ago to describe numerous infrastructures (networks) that appeared to share common features. One pioneer in the field is the historian of technology Hughes (1983) who studied electricity network, from its invention to its wide spread throughout society. This work allowed in the following years to spark interest in the research community and to gather other researchers already partly involved in this area (two important conferences were held in the eighties on this subject, leading to the publication of two books, Mayntz, Hughes, 1988, La Porte, 1991). In all these contributions, it is made explicit that beyond the electrical case studied by Hughes, it is interesting to identify a much wider category of systems, which, according to Joerges (1988, 24) '(1) are materially integrated, or 'coupled' over large spans of space and time, quite irrespective of their particular cultural, political, economic and corporate

make-up, and (2) support or sustain the functioning of very large numbers of other technical systems, whose organisations they thereby link.' For this author, examples of LTS can, as a consequence, be '*integrated transport systems, telecommunication systems, water supply systems, some energy systems, military defense systems, urban integrated public works*', etc.

Of course, with a safety perspective, a very well studied case of LTS comes to mind: aviation. From pilot's psychological models elaborated by cognitive scientists to cabin crew communication and coordination issues (leading to crew resource management programs) as well as atc studies (air traffic control) by high reliability organization researchers, there is a very large literature dedicated to the safety aspects of this LTS. However, other LTS have not been granted as much attention as aviation has been granted in the past decades of research on safety, at least to the authors knowledge. One can think of electrical grid or gas transmission networks, although serious safety issues are also associated with them. A 'black out' can have severe indirect consequences on the exploitation of highly hazardous technological installations. A recent incident in a nuclear power plant in Sweden in 2006 demonstrated this when its diesel generators failed to start as expected for cooling down the reactor's core, following a 'black out' of the electrical network supplying energy. Although an indirect consequence, the centrality of such a LTS, requires that its functioning becomes an integrated part of prevention of major hazard. As far as high pressure gas transmission networks are concerned, they can have direct (as well as indirect) consequences. One direct is the loss of containment of pressurized gas, leading, potentially, to fires.

2. THE THREAT OF 'EXTERNAL AGGRESSION'

One of the specificity of these LTS in general is that they are opened to potential 'external aggressions', voluntary or not. Pipelines are not confined within the boundaries of an industrial site. They cover a very wide geographical area, and represent in France a total of 32 000 kms. As a result, one specific safety activity that has been considered in this research is the identification and prevention by the exploiting company of 'external aggressions' on gas pipelines. For a LTS such as high pressure gas transmission network, any urban, municipal or civil engineering (umce) work carried out nearby pipelines and requiring drilling or digging with tractors is a potential threat to their integrity.

- **Ghislenghien's disaster (2004)**

The accident of Ghislenghien in Belgium in 2004 (24 persons killed, 132 severely injured) demonstrated what type of scenario could lead to major consequences. This accident was caused by a pipeline's structure weakened following an 'external aggression', which would have been caused, from a 'sharp end' point of view and according to the current explanations, by a truck involved in umce nearby. After hitting the pipeline without noticing and/or informing the operating company of the pipelines about it, the incident remained totally unknown until the pressure increased in the pipeline and that the weakened structure, where the tractor hit, failed to contain the rising pressure. It created a high pressure gas leak, and then to a huge flame when ignited by a source of energy.

This disaster is an illustration of the challenge faced by companies managing high pressure gas transmission networks for identifying, locating and assessing any works being performed nearby their pipelines. In this study, the company involved implements many levels of preventive measures ranging from national initiatives to local ones. The empirical observations have been restricted to local measures in this study. At this level, prevention is based on a decentralised mode of organising. For a given territory, a 'sector' (composed of less than 10 individuals, in this case study, it was 6) is in charge of the maintenance and the surveillance of pipelines. The sector selected by the company for the study was considered as a 'good' one, with good results and with a good image within the organisation. Located in a complex urban context of a major city, it requires a high level of interaction between many different actors including

engineering contracting and subcontracting companies, municipal employees, architects, etc.

3. OBSERVING RESILIENCE IN LTS

3.1. Elements of methodology and theory

The approach retained for describing, understanding and explaining the activity of a team within a sector involved in prevention of 'external aggression' (through the angle of resilience) relied on participant observations and interviews. Interviews were conducted with the manager of the team and then the team members, with a focus on three of them involved, directly or indirectly, in prevention of 'external aggression'. We saw them sometimes twice, in order to come back on some aspects missed in the first interview. These interviews were performed at times collectively but also individually, and oriented on specific topics, according on the function of the interviewee. Questions covered different topics including task complexity, expertise required (technical, relational) for handling work situations, relationship at work between employees and management, training, information flows about work issues and incidents, etc. Participant observations of activities within and outside the sector premises were performed, consisting in taking into account technological interfaces, communications and coordination between employees, the different steps followed for performing tasks, while interacting with employees from umce companies. When possible, some observed activities were questioned 'on the spot' (as someone learning his job would probably do). For example, following a decision that seemed to rely on a judgment that was unclear from an outsider point of view, it was asked to the employee, when possible, to explain about the rationale behind his decision.

The main purpose of these series of interviews and observations was to get close to the specificity of the work activity at the 'sharp end'. When interviews and observations were done separately by researchers, feedback sessions were organised between the observers in order to cross data, and discuss interpretations and hypotheses. Five days were spent observing and interviewing. This 'immersion' within the activity of the sector was prepared few weeks before, by a description and understanding of the more global (regulatory, economical, regulatory and political) context of this LTS. Several meetings with knowledgeable engineers and managers in this domain allowed the team of observers to get to know the context. Theoretical background for this study includes disciplines such as engineering, psychology, cognitive science, management and sociology applied to safety. The polysemous notion of resilience (Hollnagel et al, 2006) is defined in this research, at the 'team level' of investigation considered in this paper, as the adaptations (or tradeoffs) of individuals to situations within their technical and relational context, in normal operation. Resilience requires to be thought as a product of the interaction between technological, cognitive and social features.

3.2. Main safety measures for preventing external aggressions

In order to prevent 'external aggressions' on pipelines, a number of 'defense in depth' are implemented, ranging from technical to national level:

- **Technical:** increased resistance of pipelines, mechanical protection, pipelines external (yellow) signalization.
- **Regulatory:** demand of information about pipeline location by companies intending to dig (DR '*demande de renseignements*'), declaration of start of projects (DICT '*déclaration d'intention de commencement de travaux*')
- **Operational:** answer to demands of information (DR), risk assessment at work site following DICT by companies digging for umce work, surveillance of work sites and pipelines.
- **Organisational:** training of organisation's employees, information to municipalities and civil, urban or municipal engineering companies about the regulation (DR, DICT), incident analysis at national level.

It is the operational type of measures that were investigated in this case study, leaving in the background, although equally important but not discussed in this paper but partly investigated in this study.

4. Some results

4.1. A task requiring constant adaptations

One very explicit feature of the task of preventing ‘external aggressions’ appeared to be the ability of some ‘home made’ experts to adapt to daily variations of work constraints. Whereas ideally, the task was supposed to be in the form of sequential steps, (figure 1), it turned out to be of a very different kind.

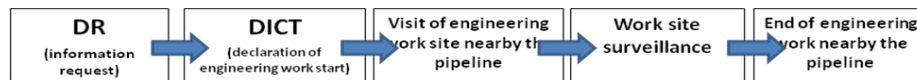


Figure 1 : a sequential task, in theory

In theory, preventing ‘external aggression’ consists in receiving an information request (a ‘DR’) by a company intending to perform umce work on a given area, asking the organisation exploiting the pipelines about the presence or not of a pipeline nearby planned umce work. If it is a positive answer, then this company must warn the organisation (through a ‘DICT’) about the intended date of start so that an employee of the LTS exploitation can come and assess the situation on site. The employee of the LTS locates then the pipeline (using a specific equipment), indicates to the umce company some safety measure to be taken given the specific situation. This agent must then wait for the end of the project to identify any damages that would have been caused to the pipeline. All this is represented in figure 2. This is however the theory. In reality, it is difficult to implement all these steps sequentially. First, there are other activities not included, such as responding to invitation from umce companies to assist them before projects start, in order to get to know where the pipelines are. But there are also emergency engineering work that are to be treated immediately (such as for example water leak to be fixed by water enginnering companies which necessitates sometimes digging close to high pressure gas pipelines). Secondly, companies performing engineering work do not always warn ahead and call the very same day that they start. As it is not planned, solutions must be made to deal with the situation, and to establish priorities among schedule. Instead of a linear sequence of activities, observations quickly reveal a different adaptive type of task, involving multiple parallel activities (figure 2).

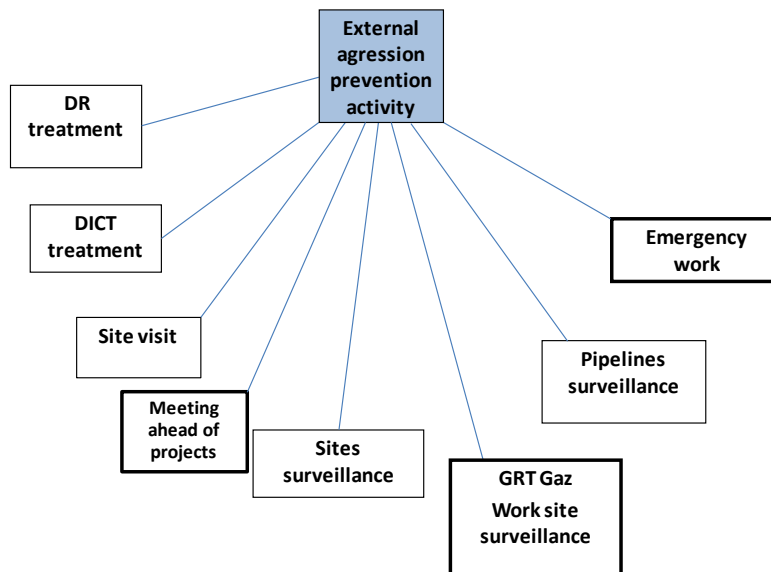


Figure 3.a task involving parallel activities

4.2. From a collective to an individual expertise

All these activities cover a wide range of different aspects and skills: administrative, relational and technical. Depending on the time of year, workload varies. In the most intensive of these periods, tradeoffs must be made between all these activities in order to allocate resources (time, expertise) for what they consider as the umce works nearby to pipelines deserving the closest watch. The coordination between the members of the team is then very important. Defined for example by Weick as one dimension of '*collective mindfulness*' (Weick, 2001), this collective side of the activity revealed in this case study interesting features among which a mix of stability and flexibility (Wildaavsky, 1988). In this team, it appeared that individual expertise was at the heart of the decision making process, when circumstances pressed for adaptive patterns. While not in the hand of the manager of the team (who hasn't got a strong experience in the field of 'external aggression' prevention), great flexibility was granted to one of the individual in the team who was acknowledged as the most expert in this area.

Organising his own schedule, he is in charge of balancing several factors for deciding in real time about the priorities when tradeoffs must be made. Of course, he relies on written procedures provided by the organisation but, given the specificity of local urban contexts, he has to adapt this procedure in order to achieve what seems to him to be a satisficing response (Simon, 1957) to his local constraints and unplanned demands. His choices have an impact on the team workload, as he can, at times, when it is required; ask a colleague (or even his manager) to replace him for a planned visit. While he is replaced, he is then able to deal with an unexpected situation, such as an emergency engineering work in a sensitive area for which he wishes to be present to ensure close supervision. This employee commented this situation as an unusual one, as he could '*give order to his own boss*'. Whereas probably in many cases one could imagine the problem of such a situation, in this team, it was not an issue. A balance had been found between hierarchy and expertise, introducing here a key issue of power in teams (and more widely, in organisations, Le Coze, 2008). This is one side of the collective expertise of the team, which partly results from the managerial style of the team leader, willing to have an expert of the team leading some decisions for the rest of team, although not a manager.

Beyond this collective side of expertise, and as a complement, what has proved also very interesting to identify and to investigate are elements of decision making process on which this individual expertise relies. Without attempting to produce a final model of such a complex topic as decision making, the strategy in this study was rather to see how collected data during interviews and observations could be exploited in order to indicate some of the key dimension of this individual expertise. In this respect, the (methodological and theoretical) approach was close to principles of 'macro cognition' or 'cognition in the wild', considering cognition to be the understood as individuals ('cleverly') adapting within their work context. Rather than expecting to fully understand cognition only through experiments (and also normative frameworks), field studies ('in the wild') become one input for the understanding of how cognition proceeds in face of complex and dynamic environments instead of simple and static ones.

4.3. Towards a heuristic model of resilience in the domain of 'external aggression'

One first step was to group together many of the data that this expert processed in his activity. A first set of six groups of key dimensions were identified. They combine many different sides implied by 'external aggression' prevention, among which 'itinerary', 'urban geography', 'pipeline', 'urban features', 'political context' and 'engineering'. Each group refers to specific topics, such as rush hour, depth of pipelines, umce companies, municipalities' services etc (figure 4). It is clear from this

description that only expertise acquired by individual from many years of experience is in a position to feel comfortable with the decision making process involved. One reason for having a specialised ‘expert’ in this team and to afford him flexibility of decision is to find an answer to this problem of knowing sufficiently well the area, the umce companies (see groups in figure 4) etc, in order to elaborate appropriate choices in real time when needed.

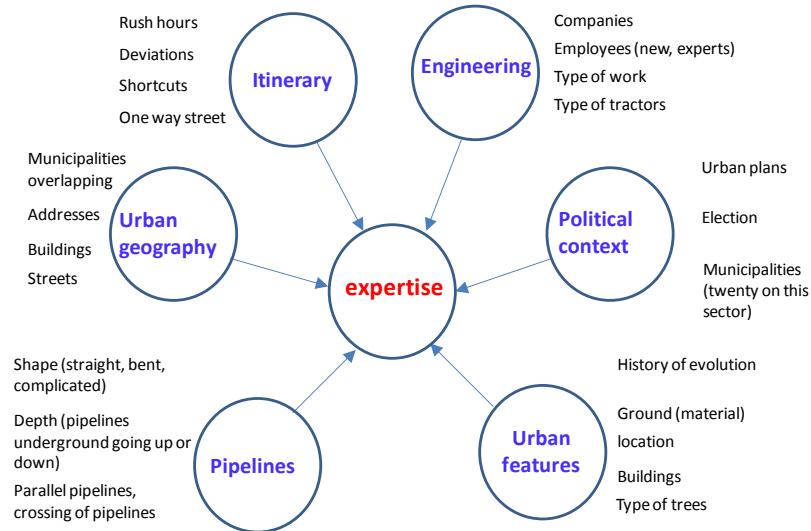


Figure 4. Expertise at the center of many different topics

One way to suggest a first model of resilience was as a consequence to introduce the notion of expertise at the heart of it, based on a combination of collective and individual expertise. For describing expertise, Klein’s approach proved useful (Klein, 1998, 2009). Synthetised through four key features: mental simulations, intuition, mastery of time horizon and knowledge by expert of his own limit, they were illustrated by some of the stories collected during observations and interviews. For example, cases of ‘intuition’ or ‘mental simulations’ were used as illustration of how expertise shaped decision making. Combining the various features of the activity together led to the followin model (figure 5). Based on a wide range of data collected by the expert on many different topics (figure 4), divided in categories of ‘global context’ and ‘specific context’, individual expertise combined with collective expertise allow the team to adjust in real time their schedule in order to maximise the chance to be at ‘the right place at the right time’.

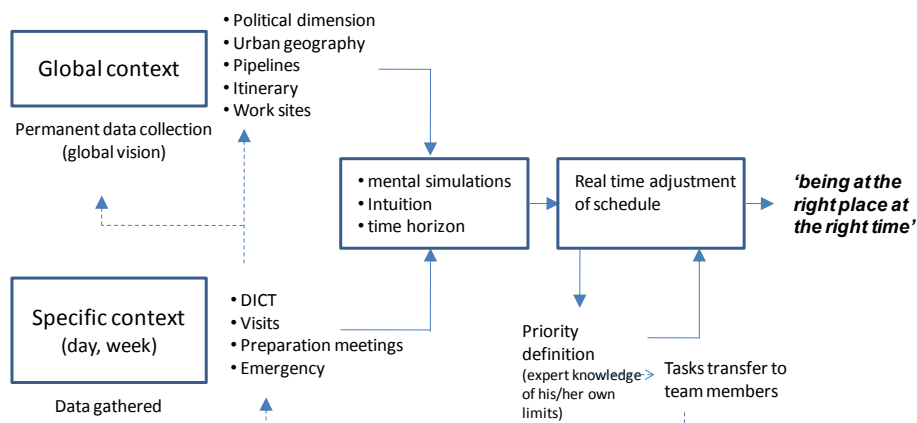


Figure 5. A heuristic model of resilience.

5. 'ENGINEERING' RESILIENCE

Beyond the attempt to model or theorise on resilience within this LTS, there are also expectations for 'engineering' solutions. This 'engineering' side is the question of how to practically enhance, support, create or maintain resilience. This study is a start. The simple and heuristic models proposed consist in some indications about what direction to pursue. One key outcome of this case study is for the work of 'external aggression' prevention by experts to access a better visibility in the organisation. Comparisons between teams should provide more data and reference points to move forward. But other concrete applications of this initial model could be translated in current incident investigations which do not explicitly rely on this type of model acknowledging the collective and individual expertise behind the scene. One other concrete use is training of managers, but also of experts in sectors. The ability to better contextualize indicators with qualitative data is also one possible prospect along with possibilities of adapting audits for them to reflect the findings of this study, rather than strict compliance with rules which is a very difficult objective for teams in such a complex and open environment. A case study on normal operation with the intent to identify and describe resilient properties of individual and teams can lead to useful and practical outcomes. However, such a translation remains part of a research problem, when model and practical ideas need to be tested to prove their relevance, implying there again strong tradeoffs between purposes of description and transformation. A good description does not necessarily lead to practical tools to help transformation (Le Coze, Pettersen, 2008).

6. CONCLUSION

This study presented here had the purpose of observing some of the features of resilience and to imagine ways of being practical in order to promote, maintain or create resilience. After describing the specificity of LTS, and associating high pressure gas transmission network to this category, the paper introduced the threat of 'external aggressions' as one activity to be studied. LTS are opened systems that need to be managed in order to cope with this specific threat. The study relied on interviews and observations for approaching what could be seen as the resilient properties of team dealing with the prevention of 'external aggressions'. The paper shows that a collective and an individual expertise, allowing flexibility and quality of decision making to be obtained, is necessary. A heuristic model, as a first attempt to capture characteristic of resilience within this LTS, has been suggested. It can serve as a basis for 'engineering' resilience, and will be completed in the future through comparisons with other sectors.

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